

AN ASSISTIVE ROBOTICS CONTROL SYSTEM BASED ON SPEECH
SEMANTIC RECOGNITION

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DEDICATION

Special dedication to my beloved parent Mohamad bin Nor and Ma Edayu binti Mahmud, siblings Ahmad Ameer and Siti Nur Atasha and friends.



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ABSTRACT

Since 90's era, many researchers and organizations are working on assistive technologies to ease the disabilities people to move around freely, independence, comfort and have the capabilities to enjoy life to the fullest. Nowadays, most of assistive technologies such as manual wheelchairs are propelled by patients sitting on the chair and physically turning the large rear wheels with hand or need helpers to push the chair by handles from behind of the wheelchair. Meanwhile, most of voice command wheelchair unable to deal with an unknown word and cannot take spontaneous speech data from the native speakers. Thus, this project proposes a method of control system for an assistive robotic based on speech semantic recognition through hardware implementation. Consequently, the purpose of this project is to develop a system based on speech semantic or meaning or the interpretation of a word, sentence, or others language form that can be used for an assistive robot. The mobile robot is represented as a wheelchair and a home prototype floor plan is represented as a house with four rooms (living room, toilet, kitchen and bedroom). The mobile robot moves according to the semantic of user commands and the commands are given on Android application Arduino Bluetooth Controller. This Android application is used to catch the command using Google Voice and send the command through Bluetooth HC-05 that connected to the Arduino. Moreover, the obstacle avoidance sensor used for this project is SHARP IR Distance Measurement sensor that standby when their obstacles in front of this mobile robot and the navigation system of this mobile robot are using Simultaneous Localization and Mapping (SLAM). The effectiveness of this mobile robot has been tested using qualitative method by gathered 12 respondents to test this mobile robot on the floor plan. The total effectiveness of this mobile robot is 83%. This mobile robot is still effective but there are some parts that are still missing and need to be improved. Finally, the main contribution of this project is to help physically handicapped people such as patients who cannot move their feet by controlling using speech meanings through helpful robotics applications.

ABSTRAK

Sejak era 90an, banyak penyelidik dan organisasi sedang berusaha meningkatkan teknologi bantuan untuk memudahkan orang kurang upaya bergerak bebas, selesa dan mempunyai keupayaan untuk menikmati kehidupan sepenuhnya. Pada masa kini, kebanyakan teknologi bantuan seperti kerusi roda manual digerakkan oleh pesakit dan secara manual mengawal tayar menggunakan tangan atau mereka memerlukan bantuan untuk menolak kerusi roda mereka. Sementara itu, kerusi roda arahan suara tidak dapat mengesan perkataan yang mereka tidak ketahui dan tidak dapat mengesan arahan spontan dari loghat bahasa lain. Oleh itu, projek ini mencadangkan satu kaedah sistem kawalan untuk robot bantuan berdasarkan pengiktirafan semantik ucapan menerusi pelaksanaan perkakasan. Oleh itu, tujuan projek ini adalah untuk membangunkan sistem berdasarkan semantic ucapan atau makna ucapan atau tafsiran perkataan, ayat, atau bentuk bahasa lain yang boleh digunakan untuk robot bantuan. Robot bergerak mewakili kerusi roda dan prototaip rumah mewakili rumah dengan empat bilik (ruang tamu, tandas, dapur dan bilik tidur). Robot mudah alih ini bergerak mengikut semantic arahan pengguna dan arahan diberikan pada aplikasi *Android Arduino Bluetooth Controller*. Aplikasi *Android* ini digunakan untuk merakam arahan menggunakan *Google Voice* dan menghantar arahan melalui *Bluetooth HC-05* yang disambungkan ke *Arduino*. Selain itu, sensor penghindaran halangan yang digunakan untuk projek ini ialah sensor *SHARP IR* sensor yang sentiasa bersedia apabila ada halangan di hadapan robot bergerak ini daripada sistem navigasi robot bergerak ini menggunakan Penyetempatan dan Pemetaan serentak (SLAM). Keberkesanan robot mudah alih ini diuji dengan menggunakan kaedah kualitatif dengan mengumpulkan 12 responden untuk menguji robot mudah alih ini di atas pelan lantai. Keberkesanan keseluruhan robot mudah alih ini adalah 83%. Akhir sekali, sumbangan utama projek ini adalah untuk membantu orang yang cacat fizikal seperti pesakit yang tidak dapat menggerakkan kakinya dengan mengawal menggunakan makna ucapan melalui aplikasi robotik yang membantu.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ω	-	Ohm
$^{\circ}$	-	degree
<i>A</i>	-	Arousal
<i>AC</i>	-	Alternating Current
<i>AI</i>	-	Artificial Intelligence
<i>ANN</i>	-	Artificial Neural Network
<i>APP</i>	-	Application Programming
<i>ARM</i>	-	Advanced RISC Machines
<i>ASR</i>	-	Automatic Speech Recognition
<i>CO</i>	-	Carbon Monoxide
<i>DAQ</i>	-	Data Acquisition
<i>DC</i>	-	Direct Current
<i>DoF</i>	-	Degree of Freedom
<i>DSS</i>	-	Drive Safe System
<i>EKF</i>	-	Extend Kalman Filter
<i>FoV</i>	-	Field of View
<i>GUI</i>	-	Graphical User Interface
<i>HMI</i>	-	Human Machine Interface
<i>HMM</i>	-	Hidden Markov
<i>ICSP</i>	-	In-circuit Serial Programming
<i>IDE</i>	-	Integrated Development Environment
<i>IoT</i>	-	Internet of Things

<i>IR</i>	-	Infrared
<i>IW</i>	-	Intelligent Wheelchair
<i>LED</i>	-	Light Emitting Diode
<i>LIS</i>	-	Lock in Syndrome
<i>LSA</i>	-	Latent Semantic Analysis
<i>M3S</i>	-	Multiple Master Multiple Slave
<i>MFCC</i>	-	Mel-Frequency Cepstral Coefficients
<i>NLP</i>	-	Natural Language Processing
<i>ORB</i>	-	Oriented FAST and rotated BRIEF
<i>PC</i>	-	Personal Computer
<i>PCB</i>	-	Printed Circuit Board
<i>POSMDS</i>	-	POSTECH Multimodal Dialog System
<i>PWM</i>	-	Pulse Width Modulation
<i>RBPF</i>	-	Rao-Blackwellized Particle Filters
<i>RFID</i>	-	Radio Frequency Identification
<i>RGB-D</i>	-	RGB and Depth
<i>RMF</i>	-	Robot Motor Factor
<i>ROS</i>	-	Robot Operating System
<i>RX</i>	-	Receive
<i>SDS</i>	-	Spoken Dialogue System
<i>SEMAFOR</i>	-	Open-source Frame-semantic Parser
<i>SI</i>	-	Speaker Independent
<i>SIRIUS</i>	-	Spiiras Interface and Integral Understanding of Speech
<i>SLAM</i>	-	Simultaneous Localization and Mapping
<i>SLU</i>	-	Spoken Language Understanding
<i>SVD</i>	-	Singular Value Decomposition
<i>TDS</i>	-	Tongue Drive System

<i>TTS</i>	-	Text to Speech
<i>TX</i>	-	Transmit
<i>USB</i>	-	Universal Serial Bus
<i>UTHM</i>	-	Universiti Tun Hussein Onn Malaysia
<i>V</i>	-	Valence
<i>V-SLAM</i>	-	Visual SLAM
<i>VFH</i>	-	Vector Field Histogram
<i>WIFI</i>	-	Wireless Fidelity



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CHAPTER 1

INTRODUCTION

1.1 Introduction

Assistive technology is a device that helps people with a disability in performing an everyday task. For example, magnifying glass and a pair of lenses is an assistive technology since it aids people with eyesight problems. There are many assistive technologies in this world until now including a specialized device such as a powered wheelchair for people who are paralysed and typing telephone for people who are deaf. When defined, assistive technology includes any piece of devices which helps in increasing the independence of disabled people. It is intended to help disabled people have the ability to see, hear, speak, learn and move about freely. Assistive technology is a growing type of technology and not new (Gaal, R P *et al.*, 1997). Many disability aids have been invented until now such as advanced technology walking products to aid people who cannot stand and even those who cannot walk. The assistive product for standing is used to aid people in the standing position while the wheeled assistive product such as wheelchair help the disabled people to increase the independence to move easily and free indoors and outdoor (World Health Organization, 2004).

Semantics is a field of linguistics that focuses on the meanings of the word and language counting the symbolic use of language. Semantic also describes the multiple meaning of words as well. The higher level of semantic language is known when there is understanding of the semantic uncertainties such as figurative language and multiple-meaning of a word (Price, C.J., 2012). Two terms correlated to semantics are connotation and denotation. The connotation referred to the meaning that related or connected or the secondary meaning of the word of expression to the first or the primary meaning. The connotation of words covers all of the feeling and impression

that follow with the use of the word. Whereas, denotation is the literal or primary meaning of the word compare to the feelings or the ideas that the word suggests. In general, semantics is the learning and study of how language is used metaphorically and accurately to deliver the meaning. There is some example of semantics. A child could be called a kid, child, son, daughter, boys, and girls. For example word the “run” comes with many different meaning. Run can be described as physically running, depart or go such as “I have to run.”, can be run a business and many more.

One of the mobile robot problems is, it is impossible for a mobile robot to be placed at an unfamiliar location in an unfamiliar environment and for the robot to incrementally create a consistent map of this environment while concurrently deciding its location within this map (Bailey, T. and Durrant-Whyte, H., 2006). Simultaneous Localization and Mapping (SLAM) is a computational problem that builds and update the map of the unfamiliar or unidentified surrounding or places whereas it is concurrently keeping track of an agent’s position within it. Though, SLAM also has to estimate the position of the agent or the robot and the map of the surrounding at the same time. In this project, in order to achieve the independence of the mobile robot to moves around freely autonomously, SLAM should work together with a mobile robot. In general, localization is known as estimating the position at the given map. Whereas, a mapping is the understanding of the map by given position. SLAM can be a little difficult because of the map are required for localization and mapping, the good position estimate is needed (Davison, A.J. *et al.*, 2007).

This research work describes the development of assistive robotics control system based on speech semantic recognition for disabled people especially paralysed person. The language used for the command in this system is the Malay language. Therefore, it is suitable for Malay speaker. When the user has desires or wants to go to some places, that user say the related word to the mobile robot and the mobile robot has to find the location itself by using visual SLAM (V-SLAM). When the user expresses their desires such as “makan”, “minum” and “lapar”, the mobile robot will go to the kitchen. This mobile robot also mounted with SHARP IR Distance Measurement sensor that acts as the obstacle detector in front of the wheelchair when it moves to a certain location.

1.2 Problem statement

The problem statements of this project are as follows:

- i. Most assistive robots nowadays are conducted using hand control, joystick or voice command direction control such as left, right, up and down but not using an autonomous wheelchair that can find the location itself according to the patient need and desires.
- ii. Wheelchair usually needs other people to push or the patients itself to move it. However, there also a patient who is semi-paralyse and no one around them. Hence, with the help of this control system, the independence of the disabled people is improved.
- iii. The voice or speech-controlled wheelchair usually got a few issues such as low understanding of the meaning rate and cannot take spontaneous speech data from the native speakers such as in Malay languages. Furthermore, that system is unable to deal with an unknown word. This research project is helping the speech-controlled wheelchair to increase the intelligence of speech-controlled wheelchair system by using speech semantic control.

1.3 Research objectives

The main objective of this project is to develop an assistive robotics control system based on speech semantic recognition.

The sub-objectives of this project are as follows:

- i. To design and develop a control system based on speech semantic for an assistive robot.
- ii. To evaluate the effectiveness of the assistive robot and its speech semantic control system.

1.4 Research scopes

There are four main limitations for this project:

i. Parameters:

- The speech semantic recognition system is for Malay speakers.
- Five simple keywords at three locations.
- “Makan”, “minum”, “dahaga”, “lapar” and “peti ais” for kitchen.
- “Buang air”, “mandi”, “basuh muka”, “wuduk” and “gosok gigi” for toilet.
- “Katil”, “tidur”, “rehat”, “tukar baju” and “solat” for bedroom.
- This project is implemented at a significant place such as house.
- The mobile robot represents a wheelchair, and floor plan prototypes represent house.
- The effectiveness of this research is tested using qualitative analysis.
- 17 respondents from UTHM’s students were picked to test the effectiveness of this system.
- 19 questions for questionnaire have been prepared and shared to the respondents during the testing session.
- This research project is being tested prototypes only to prove the SLAM method and speech semantic method used.

ii. Application:

- This project focuses on a mobile robot and its speech semantic control system.

iii. Human user

- Disabled person that is using a wheelchair.

iv. Platform and Sensors

- Arduino Mega 2560 Microcontroller
- Android Bluetooth Controller Application
- SHARP IR Sensor
- Pixy CMUCam5

REFERENCES

- Asprino, L., Gangemi, A., Nuzzolese, A.G., Presutti, V. and Russo, A., A Knowledge Management System for Assistive Robotics.
- Bailey, T. and Durrant-Whyte, H., 2006. Simultaneous localization and mapping (SLAM): Part II. *IEEE Robotics & Automation Magazine*, 13(3), pp.108-117.
- Baume, C., Plumbley, M.D., Calic, J. and Frohlich, D., 2018. A Contextual Study of Semantic Speech Editing in Radio Production. *International Journal of Human-Computer Studies*, 115, pp.67-80.
- Bayer, A.O. and Riccardi, G., 2014, December. Semantic language models for automatic speech recognition. In *Spoken Language Technology Workshop (SLT)*, 2014 IEEE, pp. 7-12. IEEE.
- Bell, D.A., Borenstein, J., Levine, S.P., Koren, Y. and Jaros, J., 1994, May. An assistive navigation system for wheelchairs based upon mobile robot obstacle avoidance. In *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, pp. 2018-2022. IEEE.
- Bonaccorsi, M., Fiorini, L., Cavallo, F., Saffiotti, A. and Dario, P., 2016. A cloud robotics solution to improve social assistive robots for active and healthy aging. *International Journal of Social Robotics*, 8(3), pp.393-408.
- Bremner, P. and Leonards, U., 2015, March. Speech and gesture emphasis effects for robotic and human communicators: a direct comparison. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction*, pp. 255-262. ACM.
- Cangelosi, A. and Ogata, T., 2016. Speech and language in humanoid robots. *Humanoid Robotics: A Reference*, pp.1-32.

- Chong, T.J., Tang, X.J., Leng, C.H., Yogeswaran, M., Ng, O.E. and Chong, Y.Z., 2015. Sensor technologies and simultaneous localization and mapping (SLAM). *Procedia Computer Science*, 76, pp.174-179.
- David L. Jaffe, MS, 2012, *Perspectives in Assistive Technology*, lecture note, ENGR110/210, Stanford University, February 2, 2012
- Davison, A.J., Reid, I.D., Molton, N.D. and Stasse, O., 2007. MonoSLAM: Real-time single camera SLAM. *IEEE Transactions on Pattern Analysis & Machine Intelligence*, (6), pp.1052-1067.
- Deng, G., Li, J., Li, W. and Wang, H., 2016, July. SLAM: Depth image information for mapping and inertial navigation system for localization. In *Intelligent Robot Systems (ACIRS), Asia-Pacific Conference*, pp. 187-191. IEEE.
- Esteves, Y.R., Concejero, J.B. and Jiménez, A.V., 2015, July. Indoor localization of the points of interest using ro-slam. In *e-Business and Telecommunications (ICETE), 2015 12th International Joint Conference*, Vol. 1, pp. 35-42. IEEE.
- Fan, Y., Han, H., Tang, Y. and Zhi, T., 2018. Dynamic objects elimination in SLAM based on image fusion. *Pattern Recognition Letters*.
- Fioretti, S., Leo, T. and Longhi, S., 2000. A navigation system for increasing the autonomy and the security of powered wheelchairs. *IEEE Transactions on rehabilitation engineering*, 8(4), pp.490-498.
- Freiha, G., Achkar, R., Owayjan, M. and Mokhadder, M., 2013, November. Smart assistive accident free wheelchair system (SAAFWS). In *Robotics, Biomimetics, and Intelligent Computational Systems (ROBIONETICS), 2013 IEEE International Conference*, pp. 67-72. IEEE.
- Gaal, R.P., Rebholtz, N., Hotchkiss, R.D. and Pfaelzer, P.F., 1997. Wheelchair rider injuries: causes and consequences for wheelchair design and selection. *Journal of rehabilitation research and development*, 34(1), pp.58-71.
- Gayathri, T.R., Aneesh, R.P. and Nayar, G.R., 2017, December. Feature based simultaneous localisation and mapping. In *Circuits and Systems (ICCS), 2017 IEEE International Conference*, pp. 419-422. IEEE.

- Gil-Gómez, J.A., Manzano-Hernández, P., Albiol-Pérez, S., Aula-Valero, C., Gil-Gómez, H. and Lozano-Quilis, J.A., 2017. USEQ: a short questionnaire for satisfaction evaluation of virtual rehabilitation systems. *Sensors*, 17(7), p.1589.
- González-Medina, D., Romero-González, C. and García-Varea, I., 2018, November. Combination of Semantic Localization and Conversational Skills for Assistive Robots. In *Workshop of Physical Agents*, pp. 56-69. Springer, Cham.
- Görer, B., Salah, A.A. and Akin, H.L., 2017. An autonomous robotic exercise tutor for elderly people. *Autonomous Robots*, 41(3), pp.657-678.
- Guo, M., Shi, P. and Yu, H., 2017, June. Development a feeding assistive robot for eating assist. In *Intelligent Robot Systems (ACIRS), 2017 2nd Asia-Pacific Conference*, pp. 299-304. IEEE.
- Hsu, Y.W., Huang, S.S. and Perng, J.W., 2018. Application of multisensor fusion to develop a personal location and 3D mapping system. *Optik*, 172, pp.328-339.
- Huo, X., Wang, J. and Ghovanloo, M., 2008, August. Wireless control of powered wheelchairs with tongue motion using tongue drive assistive technology. In *Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE*, pp. 4199-4202. IEEE.
- Jayawardena, C., Baghaei, N., Ganeshan, K. and Sarrafzadeh, A., 2013, November. Designing a socially assistive companion robotic wheel chair: RoboChair. In *Robotics, Automation and Mechatronics (RAM), 2013 6th IEEE Conference on*, pp. 231-236. IEEE.
- Ji, K., Chen, H., Di, H., Gong, J., Xiong, G., Qi, J. and Yi, T., 2018, June. CPFGL-SLAM: a Robust Simultaneous Localization and Mapping based on LIDAR in Off-Road Environment. In *2018 IEEE Intelligent Vehicles Symposium (IV)*, pp. 650-655. IEEE.
- Ji, Y., Hwang, J. and Kim, E.Y., 2013. An intelligent wheelchair using situation awareness and obstacle detection. *Procedia-social and behavioral sciences*, 97, pp.620-628.

- Jiang, X., Li, T. and Yu, Y., 2016, August. A novel SLAM algorithm with Adaptive Kalman filter. In Advanced Robotics and Mechatronics (ICARM), International Conference, pp. 107-111. IEEE.
- Kadir, H.A. and Arshad, M.R., 2016, December. Improved simultaneous localization and mapping (slam) algorithms for aerial vehicle under dynamic sea surface environment. In Underwater System Technology: Theory and Applications (USYS), IEEE International Conference, pp. 61-66. IEEE.
- Karadogan, S.G. and Larsen, J., 2012, May. Combining semantic and acoustic features for valence and arousal recognition in speech. In Cognitive Information Processing (CIP), 2012 3rd International Workshop, pp. 1-6. IEEE.
- Karan, B., Rodic, A., Vujovic, M., Stevanovic, I. and Jovanovic, M., 2016. Implementation architecture of a home robot assistant.
- Khairuddin, A.R., Talib, M.S. and Haron, H., 2015, November. Review on simultaneous localization and mapping (SLAM). In Control System, Computing and Engineering (ICCSCE), 2015 IEEE International Conference, pp. 85-90. IEEE.
- Kim, C.H. and Lee, T.J., 2018. An Application of Stereo Camera with Two Different FoVs for SLAM and Obstacle Detection. IFAC-PapersOnLine, 51(22), pp.148-153.
- Kim, C.H. and Lee, T.J., 2018. Matching Risk for Feature Selection in Visual SLAM. IFAC-PapersOnLine, 51(22), pp.144-147.
- Kim, K., Jeong, M. and Lee, G.G., 2007, August. Improving Speech Recognition Using Semantic and Reference Features in a Multimodal Dialog System. In Robot and Human interactive Communication, 2007. RO-MAN 2007. The 16th IEEE International Symposium, pp. 416-420. IEEE.
- Kotov, A., Arinkin, N., Filatov, A., Zaidelman, L. and Zinina, A., 2017, August. Semantic Comprehension System for F-2 Emotional Robot. In First International Early Research Career Enhancement School on Biologically Inspired Cognitive Architectures pp. 126-132. Springer, Cham.

- Kubota, N., 2017, September. Topological approaches for simultaneous localization and mapping. In Informatics, Electronics and Vision & 2017 7th International Symposium in Computational Medical and Health Technology (ICIEV-ISCMT), 2017 6th International Conference, pp. 1-1. IEEE.
- Lecouteux, B., Nocera, P. and Linarès, G., 2010, March. Semantic cache model driven speech recognition. In Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference, pp. 4386-4389. IEEE.
- Li, B., Munoz, J.P., Rong, X., Xiao, J., Tian, Y. and Arditi, A., 2016, October. ISANA: wearable context-aware indoor assistive navigation with obstacle avoidance for the blind. In European Conference on Computer Vision, pp. 448-462. Springer, Cham.
- Liu, S., Xing, Q., Han, Y., Zhao, Y. and Li, R., 2017, May. Speech recognition-based building semantic map method on Aldebaran Nao. In Control and Decision Conference (CCDC), 2017 29th Chinese, pp. 3539-3543. IEEE.
- Lv, Q., Ma, J., Wang, G. and Lin, H., 2016, July. Absolute scale estimation of ORB-SLAM algorithm based on laser ranging. In Control Conference (CCC), 2016 35th Chinese, pp. 10279-10283). IEEE.
- Mašek, P. and Ružicka, M., 2016. A task planner for autonomous mobile robot based on semantic network. In Advanced Mechatronics Solutions, pp. 637-642. Springer, Cham.
- Moteki, A., Yamaguchi, N., Karasudani, A. and Yoshitake, T., 2016, March. Fast and accurate relocalization for keyframe-based SLAM using geometric model selection. In Virtual Reality (VR), 2016 IEEE, pp. 235-236. IEEE.
- Nagai, A., Ishikawa, I. and Nakajima, K., 1996, May. Integration of concept-driven semantic interpretation with speech recognition. In Acoustics, Speech, and Signal Processing, 1996. ICASSP-96. Conference Proceedings, 1996 IEEE International Conference, Vol. 1, pp. 431-434. IEEE.
- Ordelman, R., De Jong, F. and Larson, M., 2009, September. Enhanced multimedia content access and exploitation using semantic speech retrieval. In Semantic

- Computing, 2009. ICSC'09. IEEE International Conference, pp. 521-528. IEEE.
- Paléologue, V., Martin, J., Pandey, A.K., Coninx, A. and Chetouani, M., 2017, August. Semantic-based interaction for teaching robot behavior compositions. In Robot and Human Interactive Communication (RO-MAN), 2017 26th IEEE International Symposium, pp. 50-55. IEEE.
- Pasteau, F., Narayanan, V.K., Babel, M. and Chaumette, F., 2016. A visual servoing approach for autonomous corridor following and doorway passing in a wheelchair. *Robotics and Autonomous Systems*, 75, pp.28-40.
- Peixoto, N., Nik, H.G. and Charkhkar, H., 2013. Voice controlled wheelchairs: Fine control by humming. *Computer methods and programs in biomedicine*, 112(1), pp.156-165.
- Posugade, V.G., Shedge, K.K. and Tikhe, C.S., 2012. Touch-screen based wheelchair system. *International Journal of Engineering Research and Applications (IJERA)*, 2(2), pp.1245-1248.
- Prabuwono, A.S., Allehaibi, K.H.S. and Kurnianingsih, K., 2017. Assistive Robotic Technology: A Review. *Computer Engineering and Applications Journal*, 6(2), pp.71-78.
- Price, C.J., 2012. A review and synthesis of the first 20 years of PET and fMRI studies of heard speech, spoken language and reading. *Neuroimage*, 62(2), pp.816-847.
- Pulka, A. and Klosowski, P., 2008, May. Polish semantic speech recognition expert system supporting electronic design system. In *Human System Interactions, 2008 Conference*, pp. 480-484. IEEE.
- Rabhi, Y., Mrabet, M. and Fnaiech, F., 2018. A facial expression-controlled wheelchair for people with disabilities. *Computer methods and programs in biomedicine*, 165, pp.89-105.

- Ronzhin, A. and Karpov, A., 2005, September. Assistive multimodal system based on speech recognition and head tracking. In Signal Processing Conference, 2005 13th European, pp. 1-4. IEEE.
- Schmidtler, J., Bengler, K., Dimear, F. and Campeau-Lecours, A., „A Questionnaire for the Evaluation of Physical Assistive Devices (QUEAD)“. In submitted to] IEEE International Conference on Systems, Man, and Cybernetics 2017, Canada, p. 54.
- Sinyukov, D.A., Li, R., Otero, N.W., Gao, R. and Padir, T., 2014, October. Augmenting a voice and facial expression control of a robotic wheelchair with assistive navigation. In Systems, Man and Cybernetics (SMC), 2014 IEEE International Conference, pp. 1088-1094. IEEE.
- Sondermann, B. and Rossmann, J., 2014, October. Simultaneous Localization and Mapping based on Semantic World Modelling. In Modelling Symposium (EMS), 2014 European, pp. 163-168. IEEE.
- Strasdat, H., Stachniss, C., Bennewitz, M. and Burgard, W., 2007. Visual bearing-only simultaneous localization and mapping with improved feature matching. In Autonome Mobile Systeme 2007, pp. 15-21. Springer, Berlin, Heidelberg.
- Tarazón, R.L., García, R.N., Aivalioti, S., Ventura, R. and Mariatos, V., 2019. Robots in Home Automation and Assistive Environments. In RADIO--Robots in Assisted Living, pp. 177-18). Springer, Cham.
- Walker, D.E., 1976. Speech understanding through syntactic and semantic analysis. IEEE Transactions on Computers, (4), pp.432-439.
- Wang, J. and Takahashi, Y., 2016, July. Particle filter based landmark mapping for SLAM of mobile robot based on RFID system. In Advanced Intelligent Mechatronics (AIM), 2016 IEEE International Conference, pp. 870-875. IEEE.
- Wang, Q. and Zhou, J., 2018. Simultaneous localization and mapping method for geomagnetic aided navigation. Optik.
- World Health Organization, 2004. International statistical classification of diseases and related health problems (Vol. 1). World Health Organization.

- Wu, C.H. and Liang, W.B., 2011. Emotion recognition of affective speech based on multiple classifiers using acoustic-prosodic information and semantic labels. *IEEE Transactions on Affective Computing*, 2(1), pp.10-21.
- Xin, G.X., Zhang, X.T., Wang, X. and Song, J., 2015, December. A RGBD SLAM algorithm combining ORB with PROSAC for indoor mobile robot. In *Computer Science and Network Technology (ICCSNT)*, 2015 4th International Conference, Vol. 1, pp. 71-74. IEEE.
- Yang, L., Song, X., Li, Y., Shan, H. and Guo, J., 2015, September. Design and Experimental Research on Intelligent Household Assistive Robot for the Elderly. In *Instrumentation and Measurement, Computer, Communication and Control (IMCCC)*, 2015 Fifth International Conference, pp. 1316-1319. IEEE.
- Yuan, W., Li, Z. and Su, C.Y., 2016, August. RGB-D sensor-based visual SLAM for localization and navigation of indoor mobile robot. In *Advanced Robotics and Mechatronics (ICARM)*, International Conference, pp. 82-87. IEEE.
- Zheng, G., Bi, S., Min, H., Yang, K. and Zhang, Y., 2017, July. Design and Implementation of Chinese Speech Robot Control System Based on Android Embedded Platform. In *2017 IEEE 7th Annual International Conference on CYBER Technology in Automation, Control, and Intelligent Systems (CYBER)*, pp. 498-503. IEEE.
- Zlatintsi, A., Rodomagoulakis, I., Koutras, P., Dometios, A.C., Pitsikalis, V., Tzafestas, C.S. and Maragos, P., 2018, April. Multimodal Signal Processing and Learning Aspects of Human-Robot Interaction for an Assistive Bathing Robot. In *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 3171-3175. IE